STATISTICAL ANALYSIS OF RESULTS FROM THE 1995 SURVEY OF CFC CONSUMPTION ON U.S. NAVY SHIPS

by

Kevin C. Burns
and
Dennis E. Smith

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DESMATICS, INC.
P.O. Box 618
State College, PA 16804

DESMATICS, INC.

P. O. Box 618
State College, PA 16804
Phone: (814) 238-9621
Fax: (814) 238-5731

Applied Research in Statistics and Systems Analysis

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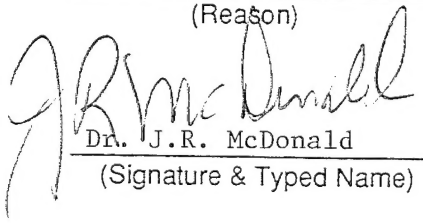

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ABSTRACT

Production of chlorofluorocarbon (CFC) refrigerants will cease in the United States at the end of 1995. The Naval Sea Systems Command (NAVSEA) needs to monitor total fleet requirements of CFCs until they are phased out. Stockpile requirements for ozone-depleting substances were determined from the results of a survey covering the period from 1 May 1993 to 30 April 1994. A second survey was conducted for the period from 1 May 1994 to 30 April 1995 for two primary reasons: to provide additional information on reserve requirements and to measure the effects of policies designed to reduce fleet CFC consumption.

This report provides a statistical analysis of the data from the new survey, which includes reported usage for CFC-11, CFC-12 and CFC-114. The new results are compared to those from the earlier survey, showing a significant reduction in CFC usage. Summary information in the report can be used to refine estimates of reserve requirements. Statistical confidence limits for CFC usage can be used to provide various levels of assurance that the reserves will not be depleted prematurely.

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1. INTRODUCTION

CFC production in the United States is scheduled to end by 1 January 1996. The Navy uses CFCs for mission-critical shipboard air-conditioning and refrigeration (AC&R) equipment. Because of this, it has established a reserve of these chemicals. This reserve must be sufficient to last until all fleet CFC systems have been retired or converted to use non-ozone-depleting substances.

CFC reserve requirements were estimated from a survey covering the period from 1 May 1993 to 30 April 1994. An analysis of the data from that survey was provided in Desmatics, Inc. Technical Report No. 157-2, August 1994. This year NAVSEA sent a second survey to all ships in the fleet requesting data for the period 1 May 1994 to 30 April 1995. Ships were asked to estimate leakage for chilled-water AC systems using CFC-11, CFC-12 or CFC-114, as well as for CFC-12 cargo and ship-stores refrigeration plants.

Respondents were asked, if possible, to separate normal leakage from losses attributable to catastrophic failures or accidental discharges. Normal leakage was defined as "the persistent loss of refrigerant through valves, seals, fittings, etc." Catastrophic losses were defined as "single-incident accidents due to system breaks and ruptures, inadvertant venting and valve openings, technician errors, etc." A copy of the survey form is included as an appendix to this report.

The survey was sent to the fleet on 12 May 1995, with a

requested response date of 15 June 1995. While most responses were received by the due date, a small number were returned in the weeks following that date. This report provides an analysis of those responses received through 18 August 1995.

2. SURVEY RESPONSE RATE

A total of 298 ships and 3 training facilities responded to the survey. The training facilities were not considered comparable to active ships and have not been used in any of the analyses. Of the 298 ship responses, there were:

242 normal responses,

11 ships which underwent extended overhauls,

4 ships inactivated during the survey period,

11 ships commissioned during the survey period,

3 ships commissioned after the survey period,

18 ships which had R-12 plants converted to HFC-134a,

2 ships (both carriers) which added R-114 plants,

6 ships which provided no leakage data because their R-12 plants had been converted to HFC-134a,

and 1 ship which provided no leakage data because it was due to be inactivated in the near future.

A list of the ship classes using relevant AC&R systems is given in Table 1. The total number of ships and the number responding to the survey are given separately for the Atlantic and Pacific fleets. These totals do not include ships which were inactivated during the survey period or commissioned after the survey period. (This excludes 4 inactivations and 3 post-survey-period commissions from the 298 total responses.) In general, the response rate was quite good, with an overall 85% response compared to 53% last year. The response rate for submarines was somewhat lower than that for surface ships (74% vs. 90%).

Inactivations, new commissions and overhauls were not used

in any of the analyses. Ships with converted or added plants were used in some analyses but not in others. When they were used, the number of plants and the plant charges were allocated in proportion to the fraction of the survey period prior to the change. These ships can be included in the summaries for the current survey, but they cannot be used in any direct ship-by-ship comparison with the earlier survey.

Not all ships use all types of systems, and some ships gave incomplete responses to the survey. For example, some ships with all R-12 AC&R equipment gave only a single R-12 usage figure, instead of individual air-conditioning usage and refrigeration usage. The number of ships used in the analysis for each type of system is given by ship class in Table 2.

3. ANALYSIS ASSUMPTIONS

In order to make inferences about fleet CFC usage during the survey period, it is necessary to make the following assumptions:

(1) The ships responding to the survey constitute a representative sample from the fleet of ships with installed AC&R plants using CFCs.

(2) The reported survey data accurately reflects actual usage during the survey period.

In order for inferences concerning future usage to be valid, two additional assumptions must be met:

(3) The variability in year-to-year usage for a given ship is the same as the variability in usage between ships in a given year.

(4) The underlying factors affecting usage do not change from year to year. (For example, there will be no modifications in maintenance policies or procedures that will alter CFC usage.)

The first assumption is reasonable as long as the data is examined separately for segments of the fleet known to have different response rates (surface vs. submarine). The second assumption is necessary and has been partially validated by data from other sources (supply system, contractor surveys). Those validations were performed for the earlier survey. It is likely that the new survey is more accurate than the earlier one because of increased awareness of the importance of the problem and improved record keeping.

The third assumption is necessary for the application of statistical confidence intervals to anticipated usage. It is equivalent to assuming that CFC usage is random and not a function of individual ship practices. As is shown in Section 5,

this assumption is not unreasonable for the available survey data.

The final assumption is probably not valid. Increasing awareness along with improved training and equipment have led to lower leakage rates. This improvement can be demonstrated for the two survey periods. However, remarks made on a few survey responses indicate that improvements were instituted during the survey period, so the current data may not reflect the full impact of those changes. Therefore, leakage rates can be expected to decrease in the future. Unfortunately, there is no way to predict the size of that decrease.

4. ANALYSIS RESULTS

In order to characterize fleet CFC usage, leakage was considered as a function of four independent variables:

(1) Fleet (Atlantic vs. Pacific),

(2) Ship Class, particularly surface vs. submarine,

(3) Plant Charge,

and (4) Commission Date.

Both normal leakage and total leakage (normal plus accidental /catastrophic) were considered as dependent variables. It should be noted that not all ships reported normal leakage and accidental/catastrophic leakage separately. It is also not clear that the leakage classifications were made consistently across ships. However, as a result of improved guidance provided in the second survey, there seems to be much less confusion than for the earlier survey.

Individual ship leakage rates were used in the investigation of relationships between leakage and the independent variables. The statistical distributions of these rates are highly skewed, and standard statistical techniques based on the assumption of a normal distribution were considered to be inappropriate. Therefore, the ranks of the rates were used rather than the actual values in searching for differences between groups of ships. The ranks follow a uniform distribution, but Analysis of Variance and other statistical techniques are much less sensitive to this type of departure from normality than they are to highly skewed distributions. This nonparametric approach also avoids problems

with outliers.

No strong relationships between leakage and either plant charge or commission date were found for any of the AC&R systems. There are significant differences between fleets for the R-12 refrigeration systems, with the Pacific fleet having lower leakage rates on average. In addition, submarines have lower R-114 AC leakage rates than do surface ships, and there are more complicated differences between ship classes for the refrigeration plants. These differences are discussed in Section 4.2.

The Navy needs to maintain a mission-critical inventory of CFCs. As part of this task, it is necessary to predict future usage and compare those predictions with the remaining stockpile quantities. Although projected usage can be based on the average leakage rates estimated from the survey, it may be desirable to ensure that there is only a small chance that the inventory will be depleted prematurely. Therefore, this report provides confidence limits for average (per ship) total leakage for each type of system.

Because of the lack of strong correlations between charge and leakage, confidence intervals were calculated by treating each set of leakage data as a simple random sample. In order to avoid making any assumptions about the statistical distributions of those samples, a nonparametric bootstrap procedure was used. This procedure involves using the observed data to estimate the probability distribution, simulating samples from that distribution, and calculating the statistic of interest for the simulated samples. It has been shown to produce good results for a wide

variety of problems. The specific technique used for this analysis incorporates bias adjustments and other corrections to produce better confidence limits.[1]

4.1 CFC-11 Chilled-Water AC Plants

The shipboard CFC data base available to Desmatics lists sixteen ships with R-11 plants. Twelve of those ships responded to the survey, but only eight gave usable responses. The other four ships included one in overhaul, one whose R-11 plant was out of commission for the entire period, and two which made no mention of R-11. The last two are aircraft carriers with one listed R-11 plant each and multiple R-114 plants.

With only eight usable responses, there is no way to detect differences between fleets or ship classes. A summary of overall leakage rates is provided in Table 3. These rates are comparable to those reported last year, but no inferences should be drawn from that fact. With such a small sample size, the average leakage rates reported here should be viewed as only rough estimates of what can be expected in the future. Confidence limits for average usage are too wide to be useful, so they are not given.

4.2 CFC-12 Refrigeration Plants

Table 4 provides a summary of reported normal leakage for refrigeration plants. There is a small difference in rates between the two fleets, but the difference is not statistically

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[1]Efron, B. (1987), "Better Bootstrap Confidence Intervals," Journal of the American Statistical Association, Vol. 82, pp. 171-185.

significant. However, there are significant differences between ship classes. The SSN-688 (Los Angeles) class have high normal leakage rates compared to the other submarines. For surface ships, it is hard to summarize the differences between classes, since there are many classes containing only a small number of ships. However, one large class, FFG-7 (Oliver Hazard Perry), stands out as having high leakage rates. Figure 1 shows leakage rates by fleet for the major ship classes.

The corresponding summary for total leakage is provided in Table 5. Differences between classes are similar to those found for normal leakage. However, for total leakage there is also a significant difference between fleets. The Pacific fleet has a lower average total leakage rate. However, as can be seen from Figure 1, that difference is not consistent across all ship classes. The difference between fleets is much larger for the DD-963 (Spruance) class than for the others.

The overall leakage rates for refrigeration plants are slightly lower than those reported last year:

	Normal Leakage	Total Leakage
1994	28.0%	56.2%
1995	24.7%	50.0%

This decrease should provide some margin of error for the CFC-12 stockpile, which was based on last year's survey data.

Some assurance that the stockpile will not be depleted prematurely can be obtained by using upper bounds on the leakage rates to project future usage. Table 6 provides confidence limits for total leakage separately for SSN-688 class submarines,

other submarines and surface ships. Since the response rate was lower for submarines than for surface ships, the sample is not completely representative. Therefore, the best procedure is to predict usage separately for the two groups. Since SSN-688 leakage rates differ substantially from those for other submarines, and the mix of the two groups will change in the future, it is also best to consider these groups separately.

4.3 CFC-12 Chilled-Water AC Plants

No significant differences between ship classes were found for CFC-12 AC leakage rates. Those rates are summarized by fleet in Table 7. On average, the Pacific fleet has lower leakage rates than the Atlantic fleet, but a t-test comparing the ranks did not yield a significant difference at the 5% significance level. The overall rates are substantially lower than those reported last year:

	Normal Leakage	Total Leakage
1994	44.2%	125.9%
1995	34.2%	73.9%

For CFC-12 AC plants, it is appropriate to base usage projections on a single average rate. Confidence limits for total leakage are also given in Table 7.

4.4 CFC-12 Total Consumption

Summary statistics for total (refrigeration plus AC) CFC-12 consumption are provided by fleet in Table 8. Also given are the reported shipboard reserve quantities. Most ships using CFC-12

AC equipment reported only a single CFC-12 reserve quantity, rather than allocating between AC and refrigeration equipment, so shipboard reserves were not included in the tables for the separate systems.

Since AC and refrigeration equipment are completely different and have different leakage rates, it does not make sense to base predictions on overall CFC-12 usage. However, the single combined average can be used as a rough initial estimate of needed reserves. Confidence limits for this quantity are provided in Table 8.

4.5 CFC-114 Chilled-Water AC Plants

Summary data for CFC-114 plants is provided in Table 9. Submarines have lower leakage rates than do surface ships for both normal and total leakage. However, only for total leakage is the difference statistically significant. There are no significant differences between the two fleets. The overall rates are lower than those reported last year:

	Normal Leakage	Total Leakage
1994	10.9%	23.9%
1995	6.6%	15.1%

Usage projections should be calculated separately for surface ships and submarines. Confidence limits for total leakage rates, along with a summary of reported shipboard reserves, are given in Table 10.

5. COMPARISON OF TWO SURVEYS

A major purpose of the second survey was to determine whether the Navy's effort to reduce CFC consumption has been effective. The response rate for the second survey was much higher than the first, and the mix of ship classes is different. These changes complicate the comparison of the overall results in the two years. The best approach to this problem is to compare results only for those ships responding in both years. Those results are summarized in Table 11. That table indicates that there are substantial decreases in leakage rates for each type of system:

	Decrease in Normal Leakage	Decrease in Total Leakage
CFC-12 Ref.	14%	23%
CFC-12 AC	66%	37%
CFC-12 Total	45%	31%
CFC-114 AC	35%	27%

These values are based only on those ships which reported in both years. However, if it is reasonable to assume that those ships are representative of the fleet as a whole, it is possible to test whether CFC consumption has been reduced throughout the fleet. Under that assumption, bootstrap resampling was used to find confidence limits for the reduction in leakage rates.

For refrigeration plant normal leakage, the change from 1994 to 1995 is not statistically significant. All of the other decreases reported above are significantly greater than zero at the 5% level. (In other words, 95% lower confidence limits for

the decreases are all greater than zero.) Assuming that the ships considered here are representative of the entire fleet, this is clear evidence that CFC consumption has been reduced in the last year.

It is of interest to determine whether reductions in leakage rates are consistent across ships. Plots of total leakage rates for refrigeration plants, CFC-12 AC plants and CFC-114 AC plants are given Figures 2 through 4, respectively. There is clearly no strong relationship between the two survey years for any of these systems. Total leakage rates decrease for some ships but increase for others, with a net overall decrease for each type of equipment.

6. USE OF THE SURVEY DATA IN MONITORING RESERVES

The summarized information provided in this report can be used to estimate depletion rates of critical CFC reserves. Since the mix of ships in the fleet is changing over time, reserve usage should be predicted separately for groups of ships with different leakage rates. Furthermore, CFC-12 reserve requirements should be determined separately for refrigeration plants and AC plants. It is recommended that reserve requirements be calculated separately for the following groups:

Refrigeration - Surface Ships, SSN-688, Other Submarines

CFC-12 AC - All Ships

CFC-114 AC - Surface Ships, Submarines

There are three main approaches that may be adopted for predicting future CFC usage. The first approach is to base the calculations on the average leakage rates. This approach provides the best estimates of the reserve depletion rates, but it does not take into account the variability inherent in those estimates. A second approach would be to base the calculations on confidence limits for the leakage rates, which provides some insurance that the requirements have not been underestimated.

A third approach would involve a study of the trade-offs between the costs, benefits and penalties of having an insufficient reserve compared with having an overstock. This approach requires economic and policy information which are outside the scope of this report.

CLASS		NUMBER IN FLEET		NUMBER IN SURVEY		FRACTION IN SURVEY	
		Atl.	Pac.	Atl.	Pac.	Atl.	Pac.
AD-37	(SAMUEL GOMPERS)	1	1	0	1	0%	100%
AD-41	(YELLOWSTONE)	2	1	2	1	100%	100%
AE-21	(SURIBACHI)	0	1	0	0	--	0%
AE-23	(NITRO)	1	0	0	0	0%	--
AE-26	(KILAUEA)	3	4	3	4	100%	100%
AGF-3	(LASALLE)	1	0	0	0	0%	--
AGF-11	(CORONADO)	0	1	0	1	--	100%
AGSS-555	(DOLPHIN)	0	1	0	0	--	0%
AO-177	(CIMARRON)	3	2	3	2	100%	100%
AOE-1	(SACRAMENTO)	2	2	2	2	100%	100%
AOE-6	(SUPPLY)	1	1	1	1	100%	100%
AOR-1	(WICHITA)	2	1	2	1	100%	100%
AR-5	(VULCAN)	0	1	0	1	--	100%
ARS-50	(SAFEGUARD)	2	2	2	2	100%	100%
AS-31	(HUNLEY)	0	1	0	1	--	100%
AS-33	(SIMON LAKE)	1	0	1	0	100%	--
AS-36	(L. Y. SPEAR)	1	1	1	0	100%	0%
AS-39	(EMORY S. LAND)	2	1	2	0	100%	0%
ATS-1	(EDENTON)	1	2	1	2	100%	100%
CG-47	(TICONDEROGA)	14	13	14	13	100%	100%
CGN-25	(BAINBRIDGE)	1	0	1	0	100%	--
CGN-36	(CALIFORNIA)	1	1	1	1	100%	100%
CGN-38	(VIRGINIA)	1	1	1	1	100%	100%
CV-59	(FORRESTAL)	0	1	0	1	--	100%
CV-63	(KITTY HAWK)	1	2	1	2	100%	100%
CV-67	(JOHN F. KENNEDY)	1	0	1	0	100%	--
CVN-65	(ENTERPRISE)	1	0	1	0	100%	--
CVN-68	(NIMITZ)	3	3	3	3	100%	100%
DD-963	(SPRUANCE)	16	15	15	15	94%	100%

Table 1: Summary of Response to the CFC Survey.

CLASS		NUMBER IN FLEET		NUMBER IN SURVEY		FRACTION IN SURVEY	
		Atl.	Pac.	Atl.	Pac.	Atl.	Pac.
DDG-51	(ARLEIGH BURKE)	5	3	4	3	80%	100%
DDG-993	(KIDD)	2	2	2	2	100%	100%
FFG-7	(OLIVER H. PERRY)	30	20	26	18	87%	90%
LCC-19	(BLUE RIDGE)	1	1	0	1	0%	100%
LHA-1	(TARAWA)	2	3	2	3	100%	100%
LHD-1	(WASP)	2	2	2	2	100%	100%
LPD-1	(RALEIGH)	1	2	1	2	100%	100%
LPD-7	(CLEVELAND)	2	4	2	2	100%	50%
LPD-14	(TRENTON)	2	0	2	0	100%	--
LPH-2	(IWO JIMA)	1	2	1	0	100%	0%
LSD-36	(ANCHORAGE)	2	3	2	2	100%	67%
LSD-41	(WHIDBEY ISLAND)	4	5	4	4	100%	80%
LST-1179	(NEWPORT)	2	2	1	2	50%	100%
MCM-1	(AVENGER)	14	0	12	0	86%	--
MCS-12	(INCHON)	1	0	1	0	100%	--
MHC-51	(OSPREY)	2	0	2	0	100%	--
SSBN-726	(OHIO)	7	8	5	7	71%	87%
SSN-594	(PERMIT)	1	0	0	0	0%	--
SSN-637	(STURGEON)	14	10	11	9	79%	90%
SSN-640	(BENJAMIN FRANKLIN)	1	1	1	1	100%	100%
SSN-671	(NARWHAL)	1	0	0	0	0%	--
SSN-688	(LOS ANGELES)	36	19	25	14	69%	74%
SURFACE		135	107	122	96	90%	90%
SUBMARINES		60	39	42	31	70%	79%
TOTALS		195	146	164	127	84%	87%
			341		291		85%

Table 1 (cont.): Summary of Response to the CFC Survey.

CLASS	COMPLETE DATA BASE	SHIPS USED	CFC-11 A/C	CFC-12 REF	CFC-12 A/C	CFC-114 A/C
AD-37	1	1	1	1		
AD-41	3	3		3		3
AE-26	7	7		7	6	
AGF-11	1	1		1	1	
AO-177	5	5		5	5	
AOE-1	4	4		4	4	1
AOE-6	3	1		1		1
AOR-1	3	2		2	2	
AR-5	1	1		1		
ARS-50	4	3		3	3	
AS-31	1	1		1	1	
AS-33	1	1	1	1		
AS-36	1	1	1	1		
AS-39	2	2		2		2
ATS-1	3	3		2	2	
CG-16	1	0				
CG-47	27	26		26		26
CGN-25	1	1		1		
CGN-36	2	2	2	2		
CGN-38	2	2		2		2
CV-59	1	1	1	1		1
CV-63	3	3	1	3		3
CV-67	1	0				
CVN-65	1	1		1		1

Table 2: Number of Useable Responses by Ship Class for Each Type of AC&R Equipment.

CLASS	COMPLETE DATA BASE	SHIPS USED	CFC-11 A/C	CFC-12 REF	CFC-12 A/C	CFC-114 A/C
CVN-68	6	6		6		6
DD-963	30	24		24		24
DDG-51	8	4		4		4
DDG-993	4	4		4		4
FFG-7	44	39		32	30	
LCC-19	1	1	1	1		1
LHA-1	5	5		5		5
LHD-1	4	3		3		3
LPD-1	3	3		1	1	
LPD-7	4	4		4	4	
LPD-14	2	2		1	1	
LPH-2	1	1		1	1	1
LSD-36	4	4		4	3	
LSD-41	8	8		8	2	5
LST-1179	3	3		3	3	
MCM-1	12	10		8	8	
MCS-12	1	0				
MHC-51	3	1			1	
SSBN-726	12	10		10		10
SSN-637	21	20		20		20
SSN-640	2	2		2		2
SSN-688	41	36		36		36
TOTAL	298	262	8	248	78	161

Table 2 (cont.): Number of Useable Responses by Ship Class for Each Type of AC&R Equipment.

	NORMAL LEAKAGE	TOTAL LEAKAGE
Number of Ships	7	8
Average Leakage	276	1889
Standard Deviation	422	4043
Minimum	0	0
Maximum	1035	11800
Charge/Ship	2507	3472
Number of Plants	24	33
Charge/Plant	731	842
Leakage/Plant	81	458
Leakage Rate	11.0%	54.4%

REPORTED RESERVES

Number of Ships	6
Number of Plants	21
Average Charge/Ship	2550
Average Charge/Plant	729
Reserve/Ship	837
Reserve/Plant	239
Reserve/Charge	33%

Table 3: Consumption of CFC-11 (lbs.) From 1 May 1994 to 30 April 1995 and Reserves as of 30 April 1995.

ATLANTIC FLEET

	FFG-7	Other Surf.	All Surf.	SSN-688	Other Sub.	All Ships
No. Ships	15	69	84	21	16	121
Average	137	178	171	67	35	135
Std. Dev.	126	280	259	76	47	225
Minimum	0	0	0	0	0	0
Maximum	365	1530	1530	300	155	1530
Charge/Ship	200	692	604	150	206	472
No. Plants	30	169	199	42	32	273
Charge/Plant	100	283	256	75	103	210
Leakage/Plant	69	73	72	33	18	60
Leakage Rate	69.3%	25.8%	28.3%	44.6%	17.1%	28.6%

PACIFIC FLEET

	FFG-7	Other Surf.	All Surf.	SSN-688	Other Sub.	All Ships
No. Ships	12	63	75	13	15	103
Average	148	158	156	67	27	126
Std. Dev.	231	210	211	86	41	190
Minimum	10	0	0	0	0	0
Maximum	820	852	852	235	150	852
Charge/Ship	200	858	752	150	194	595
No. Plants	24	163	187	26	30	243
Charge/Plant	100	331	302	75	97	252
Leakage/Plant	74	61	63	34	13	53
Leakage Rate	74.0%	18.4%	20.8%	44.8%	13.7%	21.2%

COMBINED FLEETS

	FFG-7	Other Surf.	All Surf.	SSN-688	Other Sub.	All Ships
No. Ships	27	132	159	34	31	224
Average	142	168	164	67	31	131
Std. Dev.	177	248	237	79	44	209
Minimum	0	0	0	0	0	0
Maximum	820	1530	1530	300	155	1530
Charge/Ship	200	771	674	150	200	529
No. Plants	54	332	386	68	62	516
Charge/Plant	100	307	278	75	100	230
Leakage/Plant	71	67	68	34	16	57
Leakage Rate	71.4%	21.8%	24.3%	44.7%	15.5%	24.7%

Table 4: Normal Leakage of CFC-12 (lbs.) From Ship-Stores and Cargo Refrigeration Plants From 1 May 1994 to 30 April 1995.

ATLANTIC FLEET

	FFG-7	Other Surf.	All Surf.	SSN-688	Other Sub.	All Ships
No. Ships	18	80	98	23	16	137
Average	233	416	383	128	66	303
Std. Dev.	113	632	577	145	65	507
Minimum	50	0	0	0	0	0
Maximum	430	4770	4770	547	230	4770
Charge/Ship	200	755	653	150	206	516
No. Plants	36	206	242	46	32	320
Charge/Plant	100	294	265	75	103	221
Leakage/Plant	118	162	155	64	33	130
Leakage Rate	117.6%	55.1%	58.6%	85.4%	32.2%	58.7%

PACIFIC FLEET

	FFG-7	Other Surf.	All Surf.	SSN-688	Other Sub.	All Ships
No. Ships	14	68	82	13	16	111
Average	220	329	310	103	42	247
Std. Dev.	198	477	416	87	41	374
Minimum	20	0	0	0	0	0
Maximum	820	2175	2175	235	150	2175
Charge/Ship	200	873	758	150	196	606
No. Plants	28	175	203	26	32	261
Charge/Plant	100	339	306	75	98	258
Leakage/Plant	110	128	125	52	21	105
Leakage Rate	110.2%	37.7%	40.9%	68.8%	21.2%	40.8%

COMBINED FLEETS

	FFG-7	Other Surf.	All Surf.	SSN-688	Other Sub.	All Ships
No. Ships	32	148	180	36	32	248
Average	227	376	349	119	54	278
Std. Dev.	154	555	510	127	55	453
Minimum	20	0	0	0	0	0
Maximum	820	4770	4770	547	230	4770
Charge/Ship	200	809	701	150	201	556
No. Plants	64	381	445	72	64	581
Charge/Plant	100	315	284	75	100	238
Leakage/Plant	114	146	142	60	27	119
Leakage Rate	114.4%	46.5%	49.9%	79.4%	26.8%	50.0%

Table 5: Total Leakage of CFC-12 (lbs.) From Ship-Stores and Cargo Refrigeration Plants From 1 May 1994 to 30 April 1995.

	SURFACE SHIPS		ALL SHIPS	
Confidence Level	Leakage/ Ship (lbs.)	Leakage Rate	Leakage/ Ship (lbs.)	Leakage Rate
50.0%	352	50.2%	280	50.3%
60.0%	362	51.6%	287	51.6%
70.0%	373	53.3%	296	53.2%
80.0%	387	55.3%	307	55.1%
90.0%	410	58.5%	323	58.0%
95.0%	430	61.4%	338	60.8%
99.0%	472	67.4%	367	65.9%
99.5%	493	70.4%	379	68.1%

	SSN-688 CLASS		OTHER SUBMARINES	
Confidence Level	Leakage/ Ship (lbs.)	Leakage Rate	Leakage/ Ship (lbs.)	Leakage Rate
50.0%	120	80.2%	54	27.0%
60.0%	126	83.9%	57	28.2%
70.0%	132	88.0%	59	29.6%
80.0%	140	93.1%	63	31.3%
90.0%	151	100.6%	68	33.8%
95.0%	161	107.6%	73	36.2%
99.0%	185	123.2%	81	40.4%
99.5%	193	128.4%	85	42.4%

Table 6: Confidence Limits for Average Total Leakage per Ship of CFC-12 in Ship-Stores and Cargo Refrigeration Plants.

	NORMAL LEAKAGE			TOTAL LEAKAGE		
	Atl.	Pac.	Combined	Atl.	Pac.	Combined
No. Ships	36	31	67	43	35	78
Average	295	260	279	669	510	597
Std. Dev.	386	264	333	622	471	545
Minimum	0	0	0	0	38	0
Maximum	1715	960	1715	2409	1670	2409
Charge/Ship	685	966	815	700	940	808
No. Plants	103	111	214	125	122	247
Charge/Plant	239	270	255	240	271	255
Leakage/Plant	103	73	87	229	147	189
Leakage Rate	43.0%	26.9%	34.2%	95.5%	54.2%	73.9%

TOTAL LEAKAGE CONFIDENCE LIMITS

Confidence Level	Leakage/Ship	Leakage Rate
50.0%	599	74.1%
60.0%	615	76.1%
70.0%	632	78.2%
80.0%	653	80.9%
90.0%	684	84.6%
95.0%	710	87.9%
99.0%	761	94.2%
99.5%	783	96.9%

Table 7: Consumption of CFC-12 (lbs.) in Chilled-Water AC Plants From 1 May 1994 to 30 April 1995.

	NORMAL LEAKAGE			TOTAL LEAKAGE		
	Atl.	Pac.	Combined	Atl.	Pac.	Combined
No. Ships	129	105	234	146	116	262
Average	231	206	220	510	414	467
Std. Dev.	395	315	361	734	551	660
Minimum	0	0	0	0	0	0
Maximum	2250	1780	2250	4770	2925	4770
Charge/Ship	682	898	779	732	933	821
No. Plants	409	366	775	479	417	896
Charge/Plant	215	258	235	223	260	240
Leakage/Plant	73	59	66	155	115	137
Leakage Rate	33.8%	23.0%	28.2%	69.7%	44.3%	56.9%

REPORTED RESERVES

Number of Ships	236
Number of Plants	803
Average Charge/Ship	810
Average Charge/Plant	238
Reserve/Ship	365
Reserve/Plant	107
Reserve/Charge	45%

TOTAL LEAKAGE CONFIDENCE LIMITS

Confidence Level	Leakage/Ship	Leakage Rate
50.0%	468	57.0%
60.0%	479	58.3%
70.0%	490	59.7%
80.0%	504	61.4%
90.0%	524	63.8%
95.0%	542	66.0%
99.0%	580	70.7%
99.5%	596	72.6%

Table 8: Total Consumption of CFC-12 (lbs.) From 1 May 1994 to 30 April 1995 and Reserves as of 30 April 1995.

ATLANTIC FLEET

	NORMAL LEAKAGE			TOTAL LEAKAGE		
	Surf.	Sub.	Overall	Surf.	Sub.	Overall
No. Ships	45	37	82	50	39	89
Average	222	132	181	638	220	455
Std. Dev.	307	168	257	756	359	646
Minimum	0	0	0	0	0	0
Maximum	1100	750	1100	3860	1650	3860
Charge/Ship	3463	2161	2875	3388	2180	2859
No. Plants	178	112	290	194	120	314
Charge/Plant	876	714	813	873	708	810
Leakage/Plant	56	44	51	165	71	129
Leakage Rate	6.4%	6.1%	6.3%	18.8%	10.1%	15.9%

PACIFIC FLEET

	NORMAL LEAKAGE			TOTAL LEAKAGE		
	Surf.	Sub.	Overall	Surf.	Sub.	Overall
No. Ships	38	29	67	43	29	72
Average	328	85	223	662	126	446
Std. Dev.	498	102	398	578	178	529
Minimum	0	0	0	0	0	0
Maximum	2360	350	2360	2360	875	2360
Charge/Ship	3947	2264	3219	3775	2264	3167
No. Plants	159	89	248	176	89	265
Charge/Plant	942	738	869	921	738	860
Leakage/Plant	78	28	60	162	41	121
Leakage Rate	8.3%	3.8%	6.9%	17.5%	5.5%	14.1%

COMBINED FLEETS

	NORMAL LEAKAGE			TOTAL LEAKAGE		
	Surf.	Sub.	Overall	Surf.	Sub.	Overall
No. Ships	83	66	149	93	68	161
Average	271	111	200	649	179	451
Std. Dev.	407	144	327	676	297	595
Minimum	0	0	0	0	0	0
Maximum	2360	750	2360	3860	1650	3860
Charge/Ship	3685	2206	3030	3567	2216	2996
No. Plants	337	201	538	370	209	579
Charge/Plant	907	724	839	896	721	833
Leakage/Plant	67	37	55	163	58	125
Leakage Rate	7.3%	5.1%	6.6%	18.2%	8.1%	15.1%

Table 9: Consumption of CFC-114 (lbs.) From 1 May 1994 to 30 April 1995.

REPORTED RESERVES

Number of Ships	148
Number of Plants	537
Average Charge/Ship	3040
Average Charge/Plant	837
Reserve/Ship	1379
Reserve/Plant	380
Reserve/Charge	45%

TOTAL LEAKAGE CONFIDENCE LIMITS

	SURFACE SHIPS		SUBMARINES		ALL SHIPS	
Confidence Level	Leakage /Ship	Leakage Rate	Leakage /Ship	Leakage Rate	Leakage /Ship	Leakage Rate
50.0%	651	18.3%	182	8.2%	453	15.1%
60.0%	670	18.8%	192	8.7%	465	15.5%
70.0%	690	19.3%	203	9.2%	478	16.0%
80.0%	714	20.0%	218	9.8%	494	16.5%
90.0%	750	21.0%	240	10.8%	518	17.3%
95.0%	781	21.9%	260	11.7%	538	18.0%
99.0%	838	23.5%	307	13.8%	581	19.4%
99.5%	865	24.2%	323	14.6%	597	19.9%

Table 10: Reported Reserves for CFC-114 (lbs.) as of 30 April 1995 and Confidence Limits for Yearly Total Leakage per Ship.

CFC-12 REFRIGERATION PLANTS

	NORMAL LEAKAGE 61 Ships, 142 Plants		TOTAL LEAKAGE 108 Ships, 253 Plants	
	1994	1995	1994	1995
Average Leakage	157	135	376	289
Standard Deviation	233	209	547	369
Minimum	0	0	0	0
Maximum	1215	990	3950	2143
Leakage/Plant	68	58	160	123
Leakage Rate	26.0%	22.3%	59.9%	46.0%

CFC-12 CHILLED-WATER AC PLANTS

	NORMAL LEAKAGE 14 Ships, 50 Plants		TOTAL LEAKAGE 29 Ships, 99 Plants	
	1994	1995	1994	1995
Average Leakage	446	153	1137	712
Standard Deviation	593	204	952	661
Minimum	10	0	10	38
Maximum	2250	798	3560	2409
Leakage/Plant	125	43	333	208
Leakage Rate	50.2%	17.3%	134.0%	83.9%

Table 11: Comparison of CFC Leakage Rates in Two Survey Periods. Only Those Ships Responding in Both Years Are Used in the Comparison.

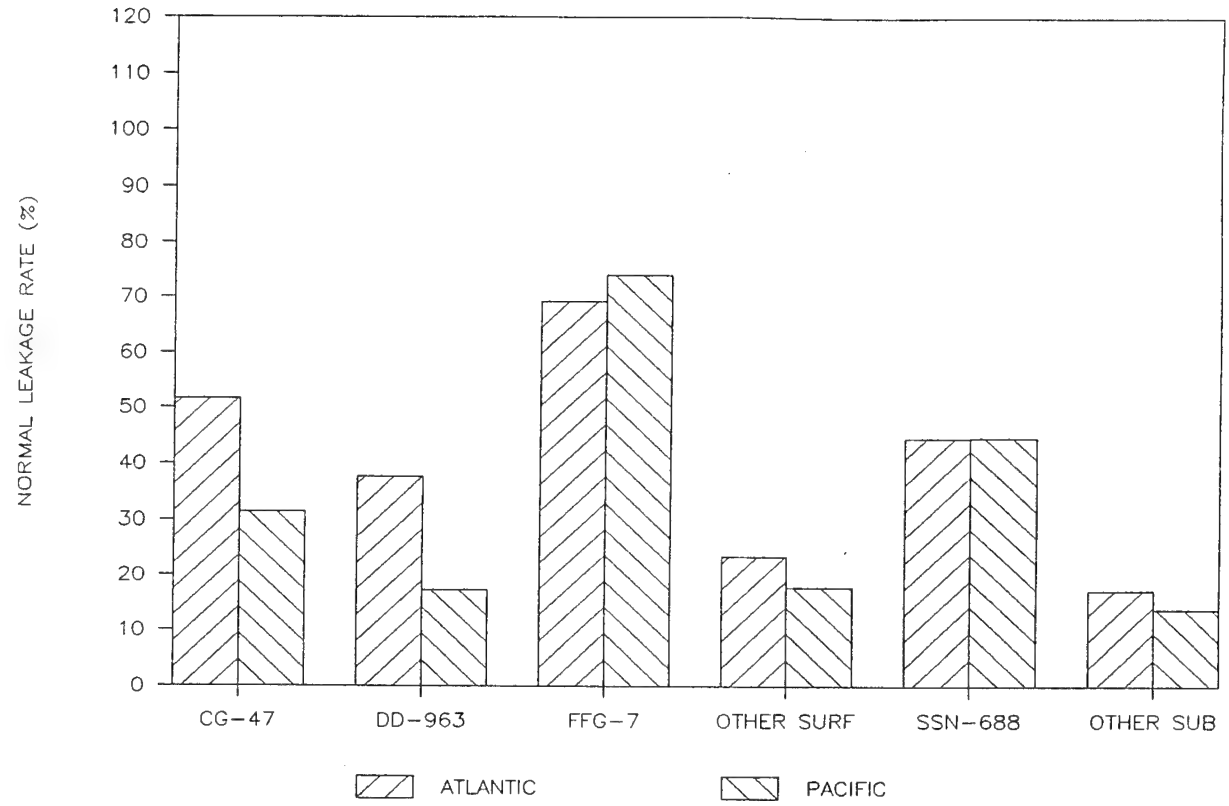
CFC-12 TOTAL CONSUMPTION

	NORMAL LEAKAGE 66 Ships, 219 Plants		TOTAL LEAKAGE 127 Ships, 463 Plants	
	1994	1995	1994	1995
Average Leakage	322	177	773	535
Standard Deviation	546	255	952	657
Minimum	0	0	0	0
Maximum	2835	1344	4325	3407
Leakage/Plant	97	53	212	147
Leakage Rate	37.1%	20.4%	81.9%	56.7%

CFC-114 CHILLED-WATER AC PLANTS

	NORMAL LEAKAGE 45 Ships, 177 Plants		TOTAL LEAKAGE 75 Ships, 284 Plants	
	1994	1995	1994	1995
Average Leakage	339	221	765	561
Standard Deviation	570	283	848	677
Minimum	0	0	0	0
Maximum	2790	1237	5500	3860
Leakage/Plant	86	56	202	148
Leakage Rate	9.3%	6.1%	23.2%	17.0%

Table 11 (cont.): Comparison of CFC Leakage Rates in Two Survey Periods. Only Those Ships Responding in Both Years Are Used in the Comparison.



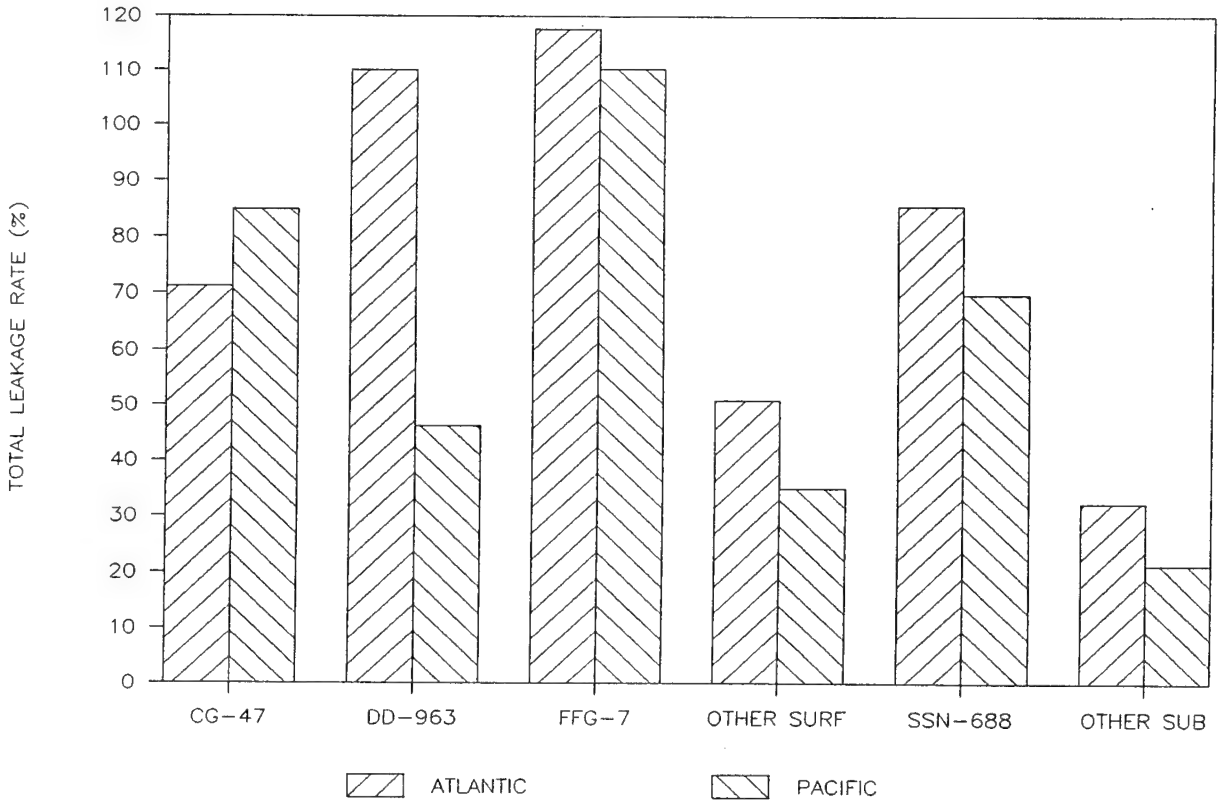


Figure 1: Refrigeration Plant Leakage Rates for Selected Ship Classes.

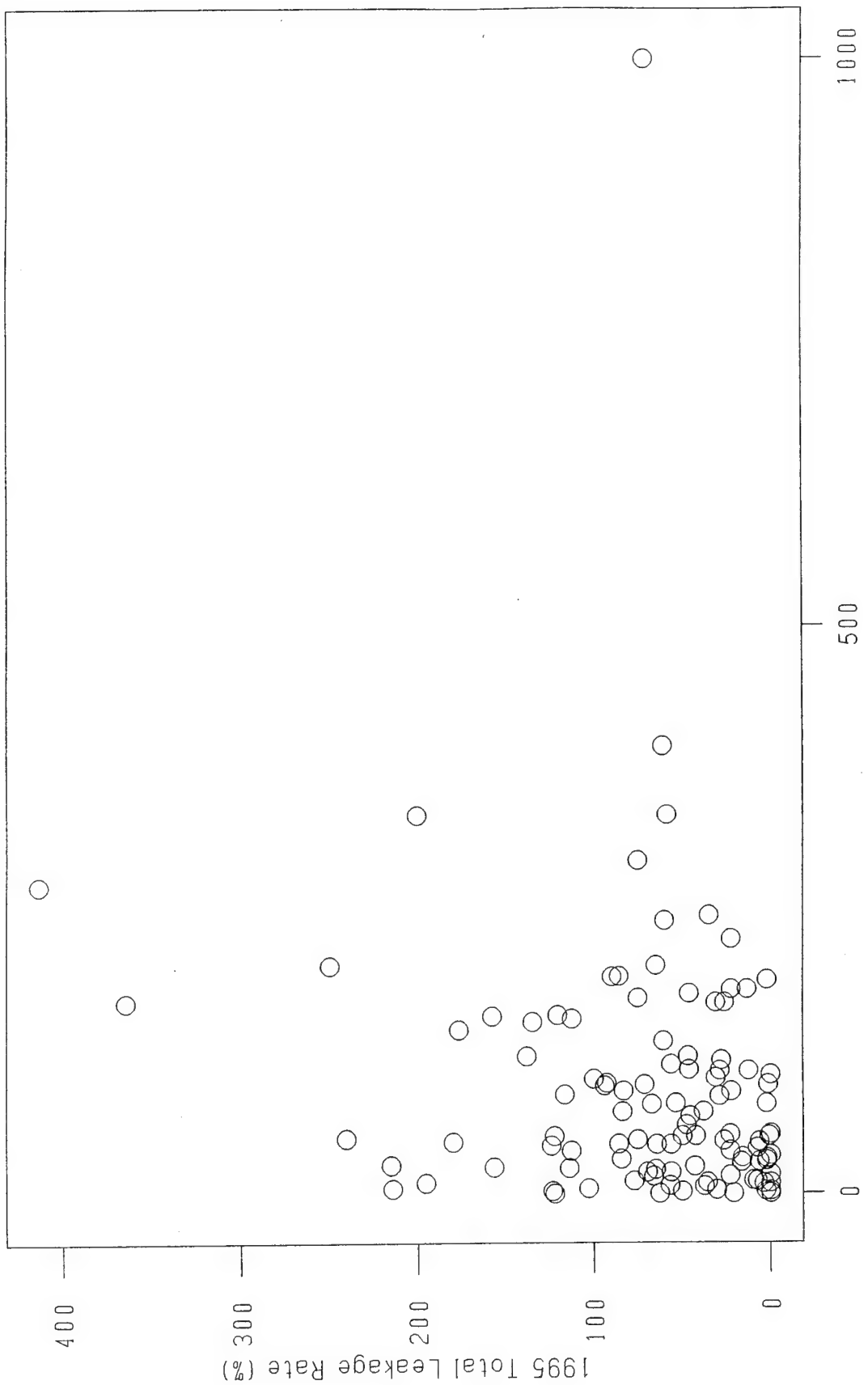


Figure 2: Comparison of Refrigeration Plant Total Leakage Rates in Two Years.

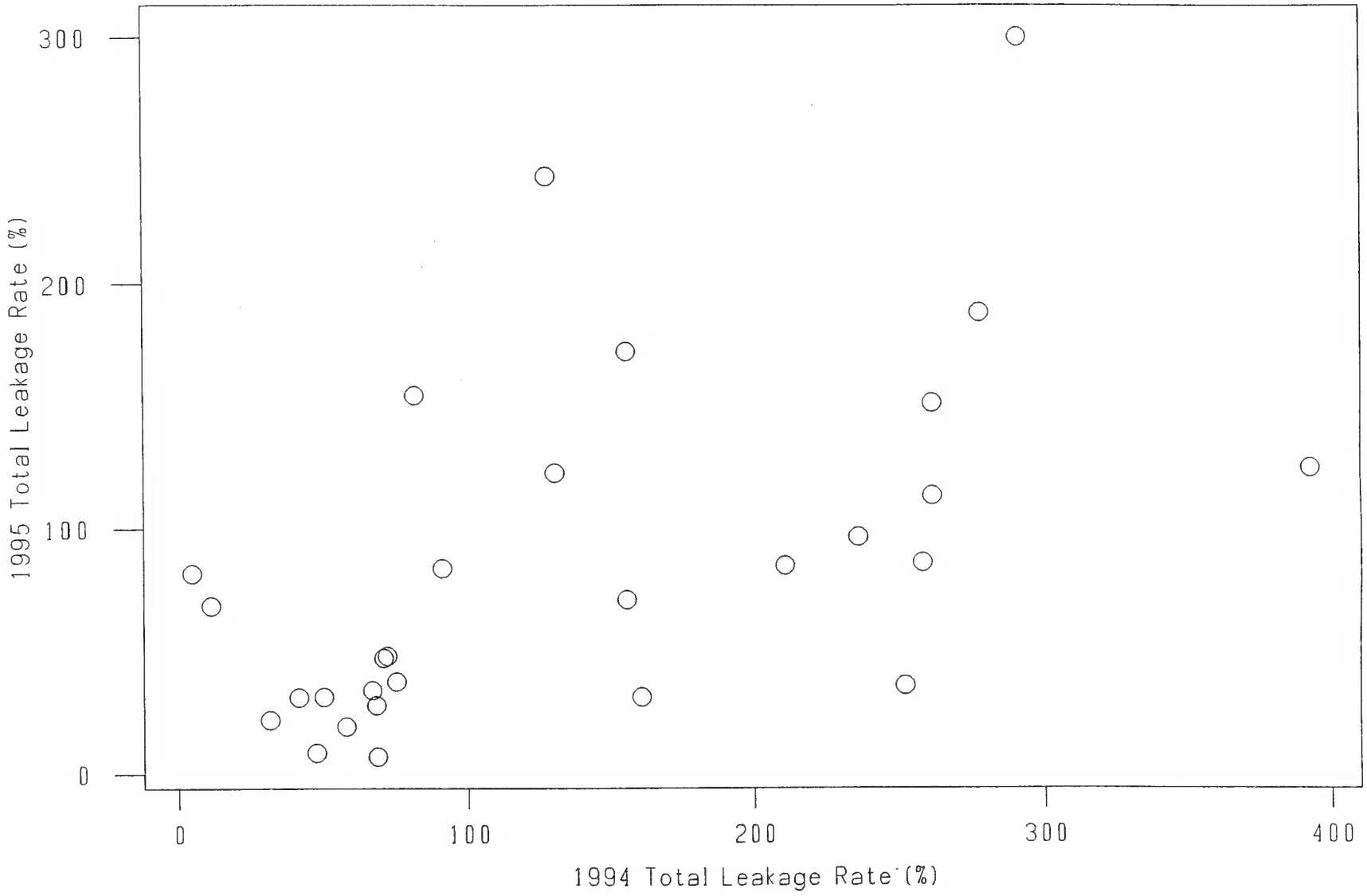


Figure 3: Comparison of CFC-12 AC Plant Total Leakage Rates in Two Years.

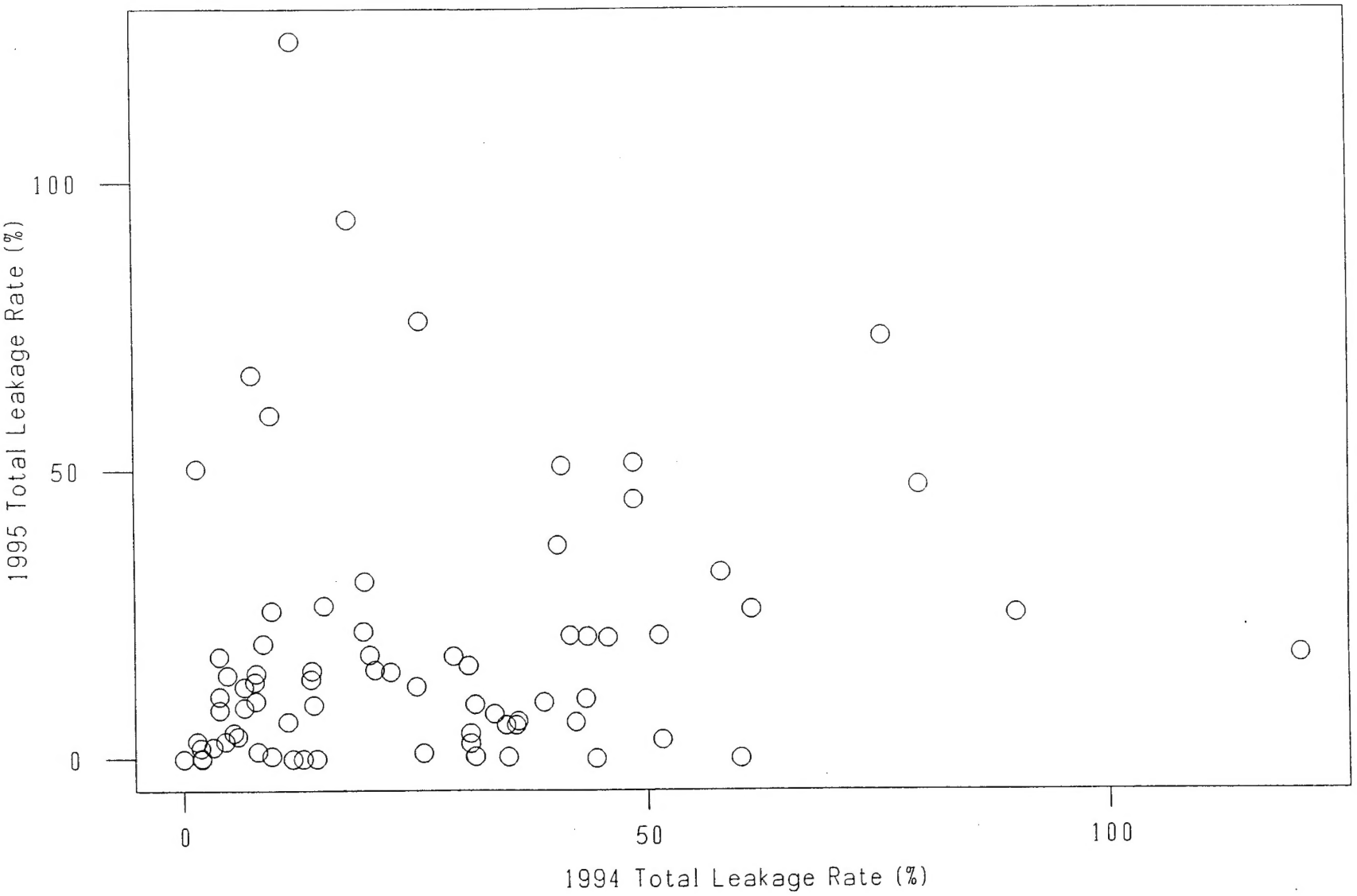


Figure 4: Comparison of CFC-114 AC Plant Total Leakage Rates in Two Years.

APPENDIX: 12 MAY 1995 SURVEY OF CFC REFRIGERANT CONSUMPTION

MSGID/GENADMIN/NAVSEA 03V24//

SUBJ/SURVEY OF CFC REFRIGERANT CONSUMPTION//

REF/A/DOC/40 CFR 82/-//
REF/B/MSG/COMNAVSEASYSCOM//090348Z MAY 94//
REF/C/MTG/CNO N4/950313//
REF/D/TEL/NAVSEA 03V24/950501//
REF/E/TEL/NAVSEA 03V24/950503//
NARR/REF A EPA FINAL RULE ON ACCELERATED PHASEOUT OF HALONS AND CFCS DTD DEC 1993. REF B COMNAVSEASYSCOM MSG SUBJ "SURVEY TO SUPPORT ESTABLISHMENT OF MISSION-CRITICAL RESERVE OF HALONS AND CFCS" COVERING 1 MAY 93 THRU 30 APR 94. REF C ENVIRONMENTAL QUALITY MANAGEMENT BOARD (EQMB) MTG CHAIRED BY CNO(N4). REF D TELCON BTWN NAVSEA 03V24 (MR. BRESLIN)/CINCLANTFLT N4654 (MS. MONINE). REF E TELCON BTWN NAVSEA 03V24 (MR. BRESLIN)/CINCPACFLT N431 (CAPT PATCH).//
POC/D. BRESLIN/SEA 03V24/-/-/TEL: 703-602-9025 X240//
AKNLDG/-//
RMKS/1. SUMMARY: THE PURPOSE OF THIS MESSAGE IS TO CONDUCT A COMPREHENSIVE SURVEY OF CFC REFRIGERANT CONSUMPTION BY FLEET IN ORDER TO MEASURE PROGRESS TOWARDS CONTROLLING OVERALL CONSUMPTION.
2. BACKGROUND: REF A ORDERS DOMESTIC PRODUCTION OF CHLOROFLUOROCARBON (CFC) REFRIGERANTS TO CEASE BY 01 JAN 96 AND PROHIBITS PURCHASE FROM FOREIGN SOURCES. DUE TO NAVY'S CONTINUED DEPENDENCE ON CFCS FOR MISSION-CRITICAL USES, DLA ESTABLISHED A MISSION-CRITICAL RESERVE DESIGNED TO CARRY NAVY FROM POINT OF PRODUCTION CESSATION TO POINT WHERE LAST CFC SYSTEMS ARE RETIRED OR CONVERTED TO NON-CFC CHEMICALS. MISSION-CRITICAL IS DEFINED AS USES WITH DIRECT IMPACT ON COMBAT MISSION CAPABILITY SUCH AS COOLING OF WEAPON SYSTEMS ON-BOARD VESSELS INCLUDING CFC-11, CFC-12, AND CFC-114 CHILLED-WATER AIR-CONDITIONING (AC) PLANTS, AND CFC-12 CARGO AND CHIP-STORES REFRIGERATION PLANTS. SIZE OF DLA RESERVE OF CFCS WAS BASED ON 1994 FLEET-WIDE CONSUMPTION SURVEY REF B.
3. IN ORDER TO ENSURE LONG-TERM VIABILITY OF RESERVE, NAVSEA IMPLEMENTED ACTIONS AIMED AT CONTROLLING REFRIGERANT CONSUMPTION. ACTIONS INCLUDE FLEET-WIDE AC&R TECHNICIAN CERTIFICATION PROGRAM, AC&R IMPROVEMENT PROGRAM ADVISORIES, AC&R TRAINING VIDEOS, ETC. REF C (CNO(N4)) DIRECTED NAVSEA TO SURVEY CURRENT FLEET REFRIGERANT CONSUMPTION TO MEASURE PROGRESS TOWARDS CONTROLLING CONSUMPTION.
4. IN ORDER TO SUPPORT REF C DIRECTION, THE FOLLOWING INFORMATION IS REQUIRED FROM ALL AFLOAT UNITS (DISREGARD THOSE SYSTEMS THAT ARE NOT APPLICABLE TO YOUR UNIT):
A. FOR SHIPBOARD CFC-11 (R-11) CHILLED-WATER AC PLANTS: REPORT TOTAL ESTIMATED CONSUMPTION OF CFC-11 BETWEEN 01 MAY 94 AND 30 APR 95 (12 MONTHS) IN LBS. IF POSSIBLE, ESTIMATE CONSUMPTION DUE TO NORMAL LEAKAGE AND CONSUMPTION DUE TO ACCIDENTAL DISCHARGES/

CATASTROPHIC FAILURES. REPORT TOTAL INSTALLED SPARE CHARGE OF CFC-11 ON 30 APR 95 IN LBS.

B. FOR SHIPBOARD CFC-12 (R-12) CHILLED-WATER AC PLANTS: REPORT TOTAL ESTIMATED CONSUMPTION OF CFC-12 BETWEEN 01 MAY 94 AND 30 APR 95 (12 MONTHS) IN LBS. IF POSSIBLE, ESTIMATE CONSUMPTION DUE TO NORMAL LEAKAGE AND CONSUMPTION DUE TO ACCIDENTAL DISCHARGES/ CATASTROPHIC FAILURES. REPORT TOTAL INSTALLED SPARE CHARGE OF CFC-12 ON 30 APR 95 IN LBS.

C. FOR SHIPBOARD CFC-12 (R-12) CARGO AND SHIP-STORES REFRIGERATION PLANTS: REPORT TOTAL ESTIMATED CONSUMPTION OF CFC-12 BETWEEN 01 MAY 94 AND 30 APR 95 (12 MONTHS) IN LBS. IF POSSIBLE, ESTIMATE CONSUMPTION DUE TO NORMAL LEAKAGE AND CONSUMPTION DUE TO ACCIDENTAL DISCHARGES/CATASTROPHIC FAILURES. REPORT TOTAL INSTALLED SPARE CHARGE OF CFC-12 ON 30 APR 95 IN LBS.

D. FOR SHIPBOARD CFC-114 (R-114) CHILLED-WATER AC PLANTS: REPORT TOTAL ESTIMATED CONSUMPTION OF CFC-114 BETWEEN 01 MAY 94 AND 30 APR 95 (12 MONTHS) IN LBS. IF POSSIBLE, ESTIMATE CONSUMPTION DUE TO NORMAL LEAKAGE AND CONSUMPTION DUE TO ACCIDENTAL DISCHARGES/ CATASTROPHIC FAILURES. REPORT TOTAL INSTALLED SPARE CHARGE OF CFC-114 ON 30 APR 95 IN LBS.

5. THE FOLLOWING GUIDANCE IS PROVIDED:

A. NORMAL LEAKAGE IS THE PERSISTENT LOSS OF REFRIGERANT THROUGH VALVES, SEALS, FITTINGS, ETC. CATASTROPHIC FAILURE LOSSES ARE SINGLE-INCIDENT ACCIDENTS DUE TO SYSTEM BREAKS AND RUPTURES, INADVERTANT VENTING AND VALVE OPENINGS, TECHNICIAN ERRORS, ETC. TOTAL CONSUMPTION IS THE SUM OF NORMAL LEAKAGE AND CATASTROPHIC FAILURE LOSSES. INFORMATION ON REFRIGERANT LOSS IN EACH OF THESE CATEGORIES IS NEEDED TO HELP IDENTIFY CORRECTIVE ACTIONS.

B. TOTAL REFRIGERANT CONSUMPTION EQUALS THE QUANTITY OF CHEMICAL USED TO REPLENISH OR CHARGE A SYSTEM LESS ANY QUANTITY RECOVERED FROM THE SYSTEM DURING MAINTENANCE OR REPAIR ACTIONS. FOR EXAMPLE, IF R-114 AC SYSTEM WAS CHARGED WITH 200 LBS OVER 12 MONTH PERIOD BUT 50 LBS WERE RECOVERED AND RETURNED TO SUPPLY DURING MAINTENANCE, TOTAL REFRIGERANT CONSUMPTION DURING YEAR IS 150 LBS. INCLUDE ALL WORK PERFORMED BY SHIP'S FORCE, NAVY MAINTENANCE AND REPAIR ACTIVITIES, AND CONTRACTORS. IF THE SYSTEM WAS SERVICED OR OVERHAULED BY AN OUTSIDE ACTIVITY DURING THE REPORTING PERIOD AND THE SYSTEM WAS REPLENISHED OR CHARGED BY THAT OUTSIDE ACTIVITY, THAT REFRIGERANT CONSUMPTION SHOULD BE INCLUDED.

C. RECOMMEND USING TECHNICIAN LOGS, MAINTENANCE LOGS, WATCH LOGS, SUPPLY RECORDS, AND ANY OTHER MEANS AVAILABLE FOR RECONSTRUCTING CONSUMPTION RECORDS. SUPPLY RECORDS INCLUDE REQUISITION FILES, DEMAND HISTORY FILES, AND PURCHASE FILES. ONLY REPORT CONSUMPTION BY SYSTEMS OWNED BY YOUR UNIT. DO NOT REPORT REFRIGERANT GIVEN TO OTHER UNITS OR ACTIVITIES. (E.G. SHIP-TO-SHIP TRANSFERS AND TURN-INS TO THE SUPPLY SYSTEM). DO NOT REPORT CONSUMPTION OF REFRIGERANT FOR PURPOSES OTHER THAN THOSE IDENTIFIED IN PARAGRAPH 4 ABOVE (E.G. GALLEY EQUIPMENT, WATER COOLERS, AUTOMOTIVE).

D. FLEET REFRIGERANT CONSUMPTION DATA IS ESSENTIAL FOR DETERMINING THE LONG-TERM VIABILITY OF THE DLA CFC RESERVE.

6. ACTION: REQUEST CINCLANTFLT AND CINCPACFLT GIVE PARAGRAPHS 4 AND 5 TO ALL AFLOAT UNITS FOR ACTION. REQUEST MSG RESPONSES FROM

ALL AFLOAT UNITS DIRECT TO NAVSEA 03V NLT 15 JUN 95.
7. THIS CONFIRMS REFS D AND E.//